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The impact of ICT sophistication on geographically distant networks: the case of space physics as seen from France

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The authors are the only responsible for the views expressed here.

Abstract:
This paper examines scientific collaboration between French public research teams and distant partners. We first analyse the role and the development of trust and then, the relation between the degree of sophistication of Information and Communication Technologies (ICT) and the constraint of geographical proximity. In that purpose, we present a typology of the different kinds of knowledge and a classification of technologies.
A case study in the field of space physics allows us to confront our theoretical elements to real life. We study the evolution of ICT sophistication parallel to collaboration patterns.
Finally, we give some recommendations for public funding of virtual networks.

Keywords: collaboratory, knowledge transfer, trust, ICT classification, space physics

1. Introduction

Knowledge is nowadays wildly acknowledged as the main source of productivity and growth. Indeed, the growth of modern economies directly relies on its production, diffusion and use (OECD, 1996). The scientific community is more and more characterised by computer-mediated communications. Just a few observations exist that have been capitalised in France for the time being. This paper deals with the creation and diffusion of knowledge in extensive

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collaboration networks, in French public research. Our analytical framework refers to the notion of collaboratory.

The key question is twofold: to assess the role and development of trust in remote collaboration; to examine the relation between the degree of sophistication of ICTs and the constraint of geographical proximity.

The first section analyses the characteristics of the interactions between scientists. We develop the dynamics of local networks through the study of knowledge transfer, the local characteristics of knowledge and trust formation and maintenance. Thus, we put into light the obstacles to distant collaboration.

The second section presents the possibilities offered by Information and Communication Technologies (ICTs) to overcome the constraint of geographical proximity. We proceed to classification of ICTs. It turns out that the diversity of technical solutions can lead to firm solutions or palliatives.

The third section is a confrontation of these theoretical elements with the real life context of a case study. The ISEE projects took the shape of an international collaboratory in space physics. We consider the French "Principal Investigator" team (at the Observatoire de Meudon), who took part in these projects, specialised in plasma physics.

The goal of this paper is to provide practical guidance for the public funding of virtual networks.

2. The dynamics of local networks

Confronted with the intense local concentration of economic activities, several economists (Jaffe (1989); Feldman (1994)) have studied the need for geographical proximity in research networks. The flourishing literature gives several reasons for this phenomenon. However, we concentrate our analysis on the ones that are particularly relevant in revealing the dynamics of public research networks.

Collaborating is both a problem of knowledge creation and diffusion. First, we analyse that the transfer of knowledge depends on its nature; then, the need for proximity differs (2.1). In a second step, we show how non-appropriability and cumulativity, two characteristics of knowledge, contribute to make local networks attractive (2.2). However, this is not sufficient if some pre-requisites are not acquired (2.3).

2.1. The transfer of knowledge

Leaving from the traditional dichotomy between tacit and codified knowledge, we present a more continuous distinction. Each of the different types of knowledge requires an adapted means of communication. The local network offers the totality of these transfer mechanisms.

From information to tacit knowledge

K. Boulding[2] considers knowledge as a structure that can be transformed or not when new messages arrive. In a similar way, E.W. Steinmueller (1999, p.9) underlines that knowledge offers the capacity to generate, extrapolate and infer new knowledge and information. Thus, knowledge is not only a stock that can grow thanks to the arrival of new messages. This conception enlarges the notion of knowledge and makes us take the learning process into

[2]Boulding (1955), as quoted by Machlup (1983)

account. As soon as we consider knowledge in a larger definition than information, it implies that there are different sorts of knowledge.

The economic literature distinguishes codified knowledge from tacit knowledge. This frequent distinction rests on the degree of knowledge accessibility and on its nature (Malerba & Orsenigo, 2000). Tacit knowledge is not, by definition, explicitly described; it is personal to the agent. Polanyi's famous sentence (1966) "We know more than we can tell" shows perfectly the notion of tacitness. In other words, we are not conscious of all the knowledge we have. Thus, tacit knowledge can be defined as "unaware, automatic and unconscious skills like mental models and heuristics used by agents for solving problems and skills used during the repetition of a specific task" (Marengo et Lazaric 2000, p.57, according to the definition by Dosi). Cowan et al. (2000) simplify the definition, considering tacit knowledge the one which "remains uncodified" (p.212). On the contrary, codified knowledge is perfectly expressed, as noted by Foray[3] (2000). It can be easily recorded and stored at low cost. It is often under the form of a text or a law. It is interesting to note that this knowledge is very close to the notion of information (Arrow, 1962). The need for communication and the will to prevent from forgetting make codification[4] necessary (cf. 3.1).

This distinction is the most common but Cowan, David and Foray (2000) have refined it. They establish that there are three forms of knowledge, according to the degree of visible manifestation: articulated, unarticulated and unarticulable knowledge. We develop the first two types but we do not consider the last one as the authors consider that it is relevant to social science.
Articulated knowledge is codified and the codebook used is perfectly visible and specific to a social context. Unarticulated knowledge does not refer explicitly to a codebook. The authors distinguish two main cases of unarticulated knowledge: when a codebook exists but it is displaced[5] and when no codebook exists. The first case refers to a situation where a manual of reference exists but it is out of sight (Cowan et al., 2000). Thus, the codebook is not explicitly manifest because it has been internalised by the group who uses it. In other words, technical terms are used in discussions but are never defined because their meaning is obvious to all the persons who are concerned. Therefore, this knowledge may seem tacit for external observers. In the second case (when there is no codebook), Cowan et al. establish an other distinction. For our concern, we will simplify it in distinguishing knowledge which is tacit but manifest (in the sense that it starts to be expressed), from "classical " tacit and latent knowledge. Manifest tacit knowledge will be associated to an unstabilised codebook.

Table 1 represents that classification, according to the degree of codification on the one hand and the degree of visibility of knowledge (manifest vs. latent) on the other hand.

[3] Codified knowledge is a « message which can be manipulated like information », (p.48).
[4] However, knowledge is codified depending on costs and benefits of codification (Cowan & al., 1997).
[5] This case is partly close to the one done by Dibiaggio (1999) between implicit and tacit knowledge. The former is about existing knowledge (codified or not) which is not explicitly invoked. That means that to create knowledge, researchers need knowledge that is implicit but very useful since without it, the system does not work.

	Manifest knowledge	*Latent knowledge*
Codified knowledge	Codebook explicit	Codebook displaced
Uncodified knowledge	Unstabilised codebook	No codebook

Table 1: Classification of knowledge according to level of codification and manifestation of knowledge
Reference: from Cowan et al. (2000), 235

It is worth noticing that over a long period, there is no definitive boundary between the four cells. In other words, knowledge with an unstabilised codebook can become perfectly codified, and latter, this codebook can be displaced. The difference between those boxes is a question of time. However, some of them can remain tacit.

Thus, leaving from the original tacit/codified distinction, we can now consider a continuum between information, codified and tacit knowledge.

Information
↓ ↑
Articulated codified knowledge
↓ ↑
Unarticulated codified knowledge
↓ ↑
Tacit knowledge

Figure 1: Continuum between information and forms of knowledge

This classification emphasizes the complementarity (vs. substitutability) of all kinds of knowledge. Each one has its own role in the creation process. Uncodified (latent or manifest) knowledge generally refers to know-how, competences and heuristics; codified (latent or manifest) knowledge more to general laws[6]. Moreover, we find four reasons of this complementarity. First, it is impossible to codify all tacit knowledge as some aspects of knowledge remain "sticky" (Von Hippel, 1994). Furthermore, tacit knowledge is necessary to use codified knowledge (and vice-versa). Besides, codification engenders new tacit knowledge. Then, there will always be a part of tacit knowledge in codified knowledge. Finally, new knowledge is always first under a tacit form. The need for exchange is the motivation for codification: the socialisation of agents makes codification necessary.

[6] Tacit knowledge refers to know-how and know-who and codified knowledge to know-what and know-why (Lundvall and Johnson, 1994).

The various means for the transfer of knowledge

The conditions of knowledge transfer vary according to its nature. The question of knowledge transfer is linked to the question of learning and understanding.

Manifest and latent codified knowledge can be acquired through reading, lecture... Transfer and learning require neither the presence (or the intervention) of another agent nor human interaction. It does not depend on the location of the agent. Thus, codified knowledge, which is in that respect comparable to information, can be easily transmitted as a message or any other formalised support, such as a scientific article (Cohendet, Llerena, 1999). This sort of knowledge can then be transmitted through a weak form of communication. However, we have to notice that "when the codebook is displaced", knowledge is difficult to transfer as, until new entrants find and acquire the codebook, it seems like tacit knowledge to them. Furthermore, this transfer can be achieved at low cost as soon as codification is done.

Uncodified knowledge is by definition not explicit, and as a consequence, it cannot be transmitted easily (Foray, 2000). This knowledge is difficult to formalise and communicate. For example, it cannot be written down as it is mainly related to competences, skills and know-how. Then, learning this knowledge entails experience through social relations and apprenticeship-relationships (Foray, Lundvall, 1996, p.20). As for latent and manifest uncodified knowledge, volunteer demonstrations by "experts" being in a same place are needed. Moreover, communication must be achieved through formal and informal channels to be efficient in this sort of transfer (cf. 3.2). Thus, the usual way of transmission is face-to-face interactions. In that respect, tacit knowledge requires geographical proximity.

As a first result, we have shown that the different forms of knowledge identified in the continuum are transmitted through different means of communication, more or less sophisticated (cf. 3.2). Thus, if codified knowledge is easily transferable from a technical viewpoint, tacit knowledge requires geographic proximity and social interactions. Consequently, the first problem to be encountered in a research network is that the existence of tacit knowledge turns geographical proximity into a constraint.

2.2. The local characteristics of knowledge

Two among the three mains economic properties of knowledge[7] reveal themselves all the more as the scientists are geographically close. Spillovers generated by the non-appropriability characteristic are more easily captured in the neighbourhood of the source of knowledge. In turn, cumulativity entails collective action, which requires interactions. Local proximity considerably facilitates them. This paragraph helps to understand the local concentration of research activity.

The non-appropriability of knowledge

Knowledge is a non-appropriable good in the sense that it is difficult to control its diffusion and use unlike that of private property. Thus, knowledge creation entails external effects that can be used for free by agents who do not belong to the creative organisation. These effects constitute knowledge spillovers[8].

[7] Non-rivalry, Non-appropriability and cumulativity.

[8] In a general way, « knowledge spillovers consist of the transmission of information (volunteer or not) which is free or which price is inferior to marginal cost" (Massard, 2001, p.11) ». This definition does not seem very well adapted to European university research as objectives in this latter activity are not lucrative but scientific. Public researchers are incited to publish their results (Cowan, Jonard, 2001).

Griliches (1993) defines spillovers as learning of what the other do. Externalities are non-pecuniary, which means that people can benefit from it without paying (Foray, 2000). Then, researchers capture externalities broadcasted by other researchers and they increase their stock of knowledge[9] (Cowan et Jonard, 2001).

Several studies (Audretsch, Feldman, 1996; Anselin, Varga, Acs, 1997) show that the existence of spillovers is one major reason for firms to locate in a place rather than elsewhere. In fact, the capacity to grab hold of externalities depends on the distance to the knowledge sources. This explains the concentration of research activities.
Indeed, geographical proximity offers several advantages. It contributes to increase the level of scientific knowledge among researchers. It allows a better access to what is going on in research activities. Thus, researchers can know easily what has been done and where to find it. Besides, local networks enable as well to save time, as what it is discovered by scientists is, by principle[10], broadcasted. Proximity allows a better access to newly created knowledge.

A study by Autant-Bernard and Massard (2000) shows that "spillovers are mediated by interactions between individuals and those interactions are facilitated by geographical proximity" (in Massard, 2001, p.13). They provide us with evidences of how spillovers, interactions and geographical proximity are narrowly linked in knowledge diffusion and creation. This remark leads us to the study of an additional characteristic of knowledge: cumulativity.

Cumulative knowledge and interactions

Knowledge use does not entail its own destruction such as a consumption good. Knowledge is both a consumption good and a production good. In other words, existing knowledge will be used to build new knowledge. In fact, most of the time, knowledge creation consists of the recombination of existing knowledge and new information, as few inventions come out from nowhere. Thus, knowledge creation always requires more knowledge, which makes it more and more diversified.
Cumulativity makes creation more collective, as no one can master all the domains of science. In turn, collective action calls for interactions, as new ideas come out from debate. Discussions allow sharing and confronting knowledge. They are more important in some phases of the process of creation such as the early phases and when the cooperation faces problems (Rallet, 1993). Then, rapid interactions allow agents to make quick decisions. They are even more efficient in a face-to-face situation as the discussion is more fluid, more interactive and denser (in the sense that face-to-face is the richest means of communication). Here, the communication between agents is also synchronised, which contributes to increasing the speed of decision-making. Furthermore, as we have already underlined, the creation process requires a wide variety in the types of knowledge, which are present in personal interactions. In that respect, proximity facilitates project coordination.

Once again, we can contemplate the dynamic properties of the local network through facilitating interactions and developing a dense research activity.

[9] This increase is a function of the absorptive capacity of agents.
[10] Some researches strongly linked with economic interests do not belong to this logic (ex: human genome, biotechnology).

2.3 Pre-requisites to cooperation

Collaboration entails the need of trust to allow to reduce incertitude and to develop efficient interactions[11]. We consider that there are two questions about trust definition: one is about the way trust is developed and with whom ; the other deals with the basis trust on which trust is granted.

The choice of partners

To answer the question of the choice of partners, Dupuy and Torre (2001) develop two notions. When people are united by common history or by the development of common rules, we are facing "community trust". It is very close to the typology by Sabel (1992), who identifies one sort of trust as originated in common history, such as same religion, same political ideas, etc.

Then the authors define inter-personal trust. It relies on learning how to identify mutual engagements and signs given to certify trust (Dupuy & Torre, 2001, p.5). That means that building trust is a process. As opposed to community trust, inter-personal trust is not given ex ante. Thus, it does not pre-exist before social relation as a free information available for everyone (Torre, 2001). Furthermore, this trust has a spatial dimension linked to the tacit and informal part of face-to-face relations.

These trusts constitute the two extreme poles, but there is a continuum in-between, where trust is characterised by more or less community trust and inter-personal trust (Torre, 2001).

The basis of trust

Local connections allow developing trust easily as relations are not anonymous. This is the case, for example, of industrial districts in which firms know each other. Geographical proximity allows the construction of trust and its consolidation thanks to the repetition of commitment[12].

Furthermore, trust enables to reduce the uncertainty that exists every time two agents develop a relationship. Uncertainty can be about the competences of the partner or on his or her intentions. The former can be easily developed *ex ante* thanks to reputation. In fact, especially in scientific community, articles, colloquies... constitute good clues to estimate the competences of a researcher. With regards to intentions, trust is more developed along the cooperation as the partner can more easily dissimulate his intentions (moral hazard). Anyway, trust refers to both of these aspects. This distinction is close to the one done by Rocco et al.(Rocco et al., 2001). They consider cognitive trust and emotional trust. The latter is more related to intentions and the former to the competences of the partners.

The existence of trust between agents allows them to consider a common future in a more efficient way. Then, trust constitutes a fundamental element of cooperation.

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[11] There is a theoretical debate about trust. In fact, if trust and collaboration are often associated, some economists consider that trust is not necessary, as a credible menace can be sufficient. Axelrod (1984) shows that Tit-for-Tat strategy is dominant in an infinite repetitive prisoner's dilemma. It is a kindly but suspicious strategy (for more information, cf. Torre, 2001)

In another view, it seems that trust is necessary in collective creative process, partly because of the particular characteristics of knowledge. As knowledge is non-rival, its use does not decrease the welfare of at least one person. Furthermore, the use of knowledge increases its value as it is a cumulative good. However, without trust, agents will hesitate to transfer their own knowledge, as it is difficult to implement efficient incentive mechanisms and menaces. Lundvall (1992) (as well as Lazaric & Lorentz, 1998) underlines that trust and honest behaviour are condition to learning.

[12] We consider that the process is the same with researchers.

Still, as underlined by Filippi and Torre (2000), putting in touch local actors is not sufficient if they previously did not interact in an organizational framework (p.74). In fact, agents must share a certain cognitive and organisational proximity. The former refers to a common base of knowledge that allows partners to technically understand each other[13]. The latter refers to the share of common organisational rules. Thus, partners have to share common knowledge about scientific issues and about the characteristics of the partners. Marengo (1998) considers that sharing common knowledge is a condition to communication and coordination. In that purpose, Foray (2000) underlines the importance of common language, each transfer of knowledge requiring a common communication system. Otherwise, partners can receive messages without understanding a word of it. If geographical proximity is a condition to collaboration, it must come with cognitive and organisational proximity. This limit allows enlarging the notion of trust in cooperation process.

As a conclusion to this section, geographical proximity enables both to solve the problem linked to the transfer of tacit knowledge as well as to stimulate public research. The local network offers advantages that make it indispensable. Thus, geographical proximity is an advantage (spillovers) as well as a constraint. Collaboration about knowledge creation cannot be efficient without trust and common knowledge.

3. ICTs vs. the proximity constraint

In the preceding section, we developed the dynamics of local networks, showing how personal interactions are of importance in collaborative science. These properties of local networks could lead to the conclusion that remote collaboration is not efficient. This section will put forward some elements that prove that assertion (at least partly) wrong, addressing the main problems set by geographical distance and the answers provided by communication technologies (3.1.). These technologies come in a rich variety. Their use in complementarity defines a model of distant collaboration, the collaboratory. To study this structure, we first need to classify the technologies according to the interaction opportunities they offer (3.2.). Finally, so as to test the ability of ICTs to overcome barriers of time and space, we formulate the two hypotheses that we will test in our case study (3.3.).

3.1. Can ICTs prevail over the barriers of remote collaboration?

Two among the many properties of local networks seem incompatible with distant collaboration: the transfer of tacit knowledge and co-ordination issues related to interpersonal interaction. Here, we try and understand in which measure technologies can help solve these problems. Indeed, the transfer of tacit knowledge may be facilitated by the use of Information and Communication Technologies (ICTs). These technologies also demonstrate properties such as to ease the remote co-ordination of complex research projects – including both trust and control. Yet, so that the diversity of tools and practices that arise from the many applications of ICTs does not lead to confusion, the learning process is highly important here.

[13] Marengo (1993) underlines the necessary trade-off between common knowledge, allowing communication (what he calls exploitation), and knowledge diversity, which favours learning and new combinations of knowledge (what he calls exploration).

The transfer of tacit knowledge

As we previously mentioned, a central concern in virtual collaboration is the transmission of knowledge among the community of researchers. Some codified knowledge is relatively easy to transmit, and can be seen as effectively diffused through general distribution channels such as scientific paper, patents, electronic mail and so on. Transmission of uncodified knowledge, and even some codified knowledge, equally necessary for the pursuit of science, is much more difficult (Cowan and Jonard, 2001). The main challenges about tacitness are that:

- The exchange, the diffusion and the learning of tacit knowledge suppose mobility and the intentional demonstration of the people who possess it. In that sense, these operations are costly and difficult to implement ;
- The research of new pieces of knowledge, complementary and proper to a special project, is strongly linked to their tacit nature. Tacit knowledge cannot be classified or listed in a systematic way.

Reducing these difficulties and risks implies codification (or explicitation). Codification is a process of conversion of knowledge into a message, which can afterwards be manipulated like information. Here, we refer to the process of moving through the frontiers between the four types of knowledge defined in table 1, towards the upper left box (codified and manifest knowledge). Codifying generates high fixed costs but enables the agents to execute further operations at a very low marginal cost. Then, codification has a strong impact on spatial organisation. Information and Communication Technologies (ICTs) appear to be a rather satisfying way to solve (at least partly) these problems. ICTs are helpful in that they considerably open the space of codifiable knowledge and at the same time raise the profitability of codification operations. D. Foray (Foray, 2000, p. 57) identifies three effects of ICTs on the codification process:

- Through encouraging the evolution in printing techniques (computers and printers, graphics software, etc.), ICTs reduce the cost of codification for easily codified knowledge;
- Through motivating the creation of new computer languages (for instance artificial intelligence) thus elevating the modelling capacity for complex phenomenon, they allow us to contemplate the possibility of codifying more and more complex knowledge (for example expert knowledge);
- As they become the physical support of a worldwide network, ICTs increase the economic value of codification, as the production of codified knowledge is strongly stimulated by these networks (networks economics dynamics).

Eventually, as we develop the arguments of an intensification of codification, we come to a first conclusion regarding the capacity of ICTs as facilitating the transfer of tacit knowledge.

Trust and control at a distance: remote co-ordination of complex research projects

In their study, which is explicitly titled "Out of sight, out of trust ", E. Rocco, T. Finholt and E. Hofer examine trust towards local and distant co-workers in a geographically distributed unit of a Fortune 100 telecommunications company (Rocco et al., 2001). They come to the conclusion that a main limitation of remote communication, which is of special interest to us, regards the level of trustworthiness embedded in long distance relationships.

More precisely, their results put a strong emphasis on the difficulty of building and maintaining emotional trust[14] through distant collaboration. Personal interaction with others

[14] The authors refer to the notion of emotional trust, which comes close to the notion of trust on the intentions, as we noticed in section 2.3. In the same way, cognitive trust will be considered as close to "trust on the

provides the opportunity to gauge their beliefs and attitudes, which is critical to accurate assessments of (emotional) trustworthiness. Distant workers have many fewer opportunities for the kinds of interaction that develop and maintain emotional trust.

On the other hand, they come to the conclusion that distant workers are not as disadvantaged in terms of communicating their reliability and competence as they are in terms of communicating emotional openness. In other words, there is not a great difference between local and long distance relationships in reading cues associated with cognitive trust. For example (Rocco et al., 2001, p. 12) attributions about reliability may be reinforced as easily by a prompt email reply or a telephone call (i.e. as in geographically distributed teams) as by a prompt visit in response to a note left on a office door (i.e. in a local team). In a similar vein, judgements of competence are based on the correct execution of tasks depending on the worker's skills and not on his or her location.

These results give us some clues so as to formulate strategies to improve trust formation and maintenance at distance through ICTs. Technical solutions could potentially reduce the dependence on face-to-face interactions. For instance, the positive correlation between phone use and frequency of long distance non-work communication (another result of Rocco et al.) suggests that technologies that are richer in terms of immediacy of the feedback (for instance, that incorporate features of the phone conversation) and available channels for interpreting communication cues, may perform more effectively in terms of fostering emotional trust (Daft and Lengel, 1984, 1986). The development of tools for richer social interactions at a distance (such as a "virtual jazz cub", mentioned by Boyer, Vernick, Wilbur, Kahn and Balfour, 1999) is another example.

Besides trust, another issue at stake is the ability to manage and support complex group work in virtual settings. It is all about solving problems of individual and group behaviour, all the more difficult as distance grows. Overcoming these co-ordination barriers represent a great challenge. Here again, Rocco et al. refer to potential ICT solutions so as to reinforce hierarchy at a distance. In terms of generating a super-ordinate identity, some organisations exploit web-based solutions; such is the web newspaper application used at Apple©'s advanced Technology Group, where people can post new items to a group Web page viewable from desktops and from various public locations, such as lounges (Houde, Bellamy and Leahly, 1998).

From these examples, a twofold preliminary conclusion could be drawn. Considering cognitive trust, technologies do seem to overcome distance and time barriers. As for the capacity of technologies to achieve both trust formation and maintenance and to allow the co-ordination of research projects at a distance, the results bring us to a less firm conclusion. It seems that ICTs provide us with solutions that, up to today, are only palliatives.

The diversity of remote communication tools and patterns

One suggestion from a small number of studies, which the previous elements corroborate, is that electronic communication alone may not be enough to enable a broader range of collaboration in science (Walsh and Roselle, 1999; Rafaeli, Sudweeks, Konstan and Mabry, 1998; Orlikowski and Yates, 1994). That is, while communication is undoubtedly important in fostering and sustaining successful scientific collaborations, joint research work also

competences". From this point on, we will only consider "emotional" and "cognitive" trust, as these are the terms employed by the authors we refer to.

requires access to specialised equipment and unique datasets. As T. Finholt puts it " Broad collaboration in science requires the elaboration of additional network capabilities, particularly applications that enhance sharing of data and visualisations, and applications that allow remote use of important instruments and facilities." (Finholt, 2001, p. 7).

Consequently, communication tools and patterns among scientists become more and more diversified, multipolar. Yet, that richness must not lead to confusion. The learning process of doing remote research through ICTs is of importance in that respect, even more if the field of research requires sophisticated infrastructures (we mean here that it is easier to set to e-mail than to remote telescope operating). Researchers have to learn how to adapt the very wide range of communication patterns to the nature of their object, some very old and some high-tech, formal or informal, synchrone or asynchrone, written or oral (de la Vega, 1998). With respect to that point, bringing together computer scientists and remote network members can help foster the learning process. The addition of learning by doing (on the computer scientists' side) and learning by using (on the network members' side) may produce differential benefits in remote collaboration. Moreover, as we will see it in our case study, the development of new patterns of knowledge production has added another function to information professionals. Besides their traditional role of knowledge stock managers, they now need to manage knowledge flows (Turner, 1993).

To resume this section, we could say that ICTs, in their diversity, offer us answers to the many obstacles of remote collaboration. Whether these answers are real solutions that definitely remove the difficulties or simple palliatives, they nonetheless open the floor to more efficient geographically distant collaborations.

3.2. A classification of ICTs

The many technologies we just evoked are often used in a complementary manner. The pattern of using them as such defines a structure called a "collaboratory" (Wulf, 1989). As this structure clearly has to face the same barriers as we previously mentioned, it will become our framework for distant collaboration. Yet, before we go further on, we need to classify and organise the many technologies that are made use of in collaboratories. We propose a classification that is adapted to our purpose of evaluating the impact of technologies on overcoming time and space barriers.

A model of distant collaboration: the collaboratory

Nearly two decades of technology evolution have led to a rich variety of computers and network tools for the support of collaborative work. Combination of these existing tools, with the elaboration of some new tools, form the core capabilities that constitute a collaboratory. First proposed by visionary scientists in the late eighties, it is defined as "… a centre without walls, in which researchers can perform their research without regard to physical location … interacting with colleagues, accessing instrumentation, sharing data and computational resources, and accessing information in digital libraries" (Wulf, 1989, p. 19, as quoted in Finholt, 2001, p. 7). This term is a hybrid of collaborate and laboratory. Hence, the elaboration of the collaboratory concept stresses the simultaneous need to solve problems of control and operation of instrumentation over the Internet, of access and distribution of datasets, and of convenient and flexible interactions with colleagues[15]. The structure of

[15] On that purpose, we can note that collaboratories offer the opportunity for round the clock collaboration. A researcher can spend the day working on a paper and send it to his American colleague. This colleague does the

collaboratory has to tackle with all the barriers we mentioned in the previous section. We will thus consider that structure as our framework for distant collaboration.

To clarify our analysis of the impact of ICTs on distant collaboration, we now need to organise and classify the many technologies employed in a collaboratory. In that purpose, we chose to associate two complementary approaches.

The sophistication of technologies

As defined by Atkins (1993), the capabilities used in a collaboratory can be defined as technology to link people with information, technology to link people with people and technology to link people with facilities. Technologies to link people with information have recently experienced tremendous growth in sophistication and use, including web sites and digital libraries. Examples of people-to-people technologies include familiar applications, such as electronic mail, and tools for data conferencing. Finally, technologies to link people to facilities include data viewers that display the current mode and status of remote instruments as well as services that provide scientifically critical data.

This first categorisation does not allow us to fix any order, as each category includes more or less sophisticated technologies. A representation of the categories comes as such:

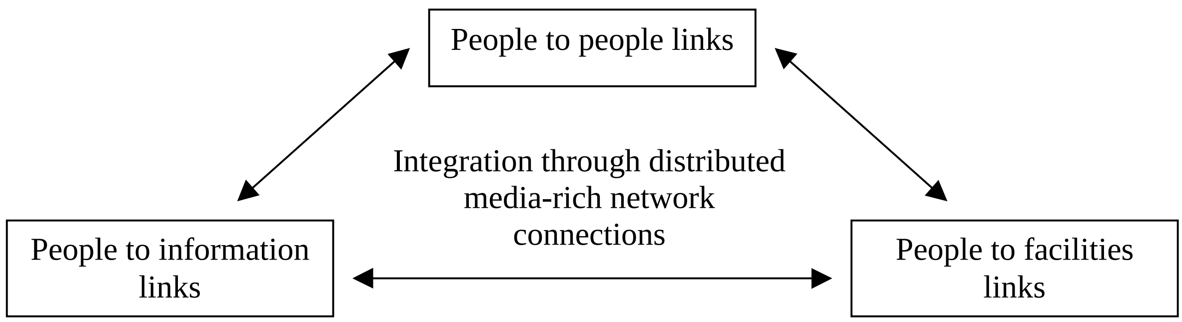

Figure 2. The three categories of technologies as by Atkins (1993)
Reference: *Finholt (2001) 49*

Still, that classification of technologies is not sufficient for the purpose of our study. As we noticed earlier, the needs for an immediacy of feedback and available channels for interpreting communication cues are important in reducing the barriers to remote collaboration. Technologies that incorporate synchronisation allow informal and spontaneous communication with remote colleagues. Rocco et al. state in their study that in many cases, distance equalled delay because important decisions were made in informal circumstances (e.g., in the corridor or in front of the coffee machine), "leaving remote colleagues in the dark" (Rocco et al., 2001, p 9). Even though that assertion was made in the case of non-research collaborations, we hold it for true in collaboratories. Indeed, research collaboration also has to deal with organisational and emotional trust issues that stress the importance of the speed of feedback (see section 3.1.). Moreover, synchronisation is very important for

same and send the document to an Australian or Japanese colleague at the end of his working day. This last scientist can then transmit the paper back to his European partner, who will find it when he arrives at work. Our interviewee mentioned that three-time-zone collaborations are possible, even though the norm is two-time-zone.

scientific discussions, when each of the discussant is teeming with ideas and needs to transmit and validate his or her ideas. In that respect, we are akin the ideas developed in section 2.2., dealing with the cumulativeness of knowledge, and the beneficial rapid interactions.
As for communication cues, we can find very interesting results from a study by Bos, Gergle, Olson and Olson (Bos et al., 2001)[16]. They confirm our intuitive feelings of a plausible classification of technologies with regards to trust formation. Their experience did not deal with the same notion of trust as ours; they consider a "lighter" trust than we do, as they worked on a social dilemma game, and not a long-term scientific cooperation. Still, keeping it in mind, they provide us with interesting elements. They showed that videoconferencing may be as good as face-to-face for building (light) trust. In their experiment, video was indistinguishable from face-to-face, and both were better than text chat. Although the authors cannot statistically separate the phone conditions, it appears that phone is somewhere in between text chat and video for (light) trust building. It does appear that (light) trust forms more slowly in mediated conditions. Leaving from these results, we propose an index for the quality of communication (with respect to the formation of trust,) allowed by the technologies. Even if we do not consider the same notion of trust than Bos et al., we assume that the quality of the communication channels remains comparable. It comes as such:

Communication channel	Text <	Sound <	Image	(< face-to-face)
Associated « quality » index	1	2	3	(Max)

Table 2. Communication channel and their associated quality index

To sum it up, and for each of the categories of technologies, we defined two criteria: the speed of feedback (the upper extreme being synchronisation) and the quality of the media as regarding trust formation. These classification cues help us ordering the technologies according to what we will consider their « degree of sophistication ». This degree is positively correlated to the speed of feedback and to the quality index of the communication channel. Then, the degree of sophistication is given by a simple measure of distance.

This second classification cues help us ordering the technologies regarding their "sophistication" as related to the immediacy of feedback and nature of channels. We will define sophistication as positively correlated to the speed of feedback of the technology and to the "quality" of channels. Then, the degree of sophistication is given by a simple measure of distance (from the origin of the graph to the technology). These classification cues are the same for each of the three categories defined by Atkins.

An illustration of this classification of ICTs, for the case of people to people technologies, comes as in the following example.

We consider the following four technologies: e-mail, telephone, chat, videoconference. Each of them is characterised by its available communication channels and a certain speed of feedback, represented in the following table:

[16] They studied the emergence of trust in a social dilemma game in four different communication situations: face-to-face, video, audio, and text chat. Three-person groups did 30 rounds of a social dilemma game and they measured trust by the extent to which people co-operated vs. competed.

	e-mail	Telephone	Chat	Videoconference
index of channels	1	2	1	4
	(text only)	(sound only)	(text only)	(text, sound and image)
Synchronisation ?	No	Yes	Yes	Yes

Table 3. Characteristics of four « people to people » technologies

In the case of videoconference, we have the addition of text, image and sound. We will then consider a higher index of quality than 3.

The classification then comes as such:

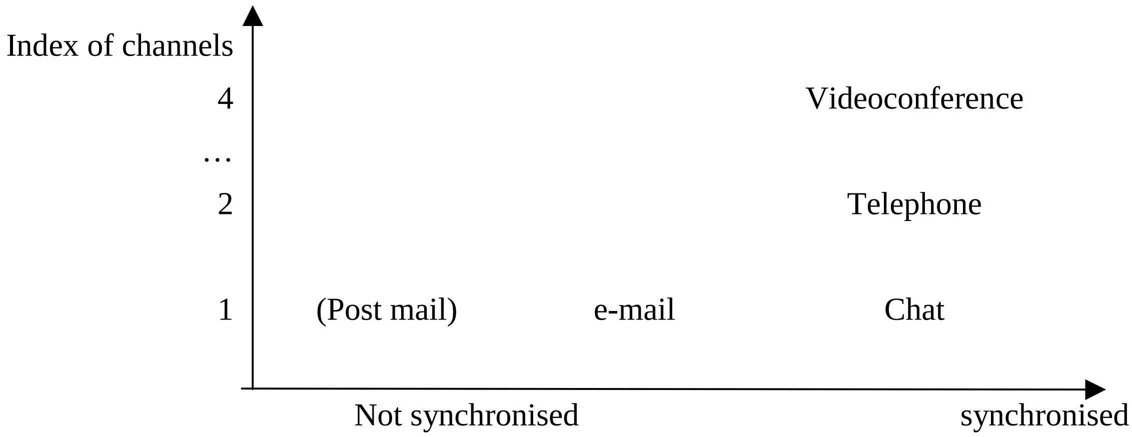

Figure 3. A classification of four technologies that link people to people

This classification will help us understand the impact of sophistication on overcoming the difficulties we mentioned in section 3.1. We will try and see the complementarities and substituabilities among them. As a first indication given by table 2, we can already imagine that substitutability will be achievable only for equally sophisticated technologies.

3.3. Our hypothesis

The notion of science as (geographically) distributed intelligence relies heavily on information technology to overcome barriers of time and space. Our analysis of the literature (mainly by researchers at the University of Michigan), led us to consider two main hypotheses so as to test the impact of ICTs on distant collaboration. The first one deals with the "trust issue" and the virtual impossibility of building 'emotional' trust at a distance. The second one deals more strictly with the issue of time and space, assuming the equivalence of sophisticated technologies with face-to-face interactions.

"Trust needs touch" hypothesis

As Rocco et al. mention it in their article, there is a non technology-transposable component in the elaboration of trust, which is face to face interaction. They provide clear arguments for the benefits associated with visiting distant sites[17]. We can formulate our first hypothesis as such:

H1: The elaboration of trust is a necessary starting condition to virtual collaborations, which can only be achieved through face to face interviews;

We have put forward proposals against that hypothesis (synchronised and high quality media could allow the formation of trust), but we still have to test if they are palliatives or real substitutes to face to face.

The peripherality hypothesis

According to the peripherality hypothesis (Sproull and Kiesler, 1991, p. 95), the introduction of electronic communication may produce universal benefits for those who are relatively disadvantaged. For instance electronic mail, bulletin boards and mailing lists allow peripheral colleagues to have the same access to important activities and knowledge flows as centrally located members of the network, such as those in "headquarters" sites (Rocco et al., 2001). In the peripherality hypothesis, a hope for collaboratory elaboration and use is that improved access to important but scarce instruments and data, combined with easy communication among researchers, will diminish barriers of status, time and space that hamper scientific progress (Finholt, 2001).

We stated the whole hypothesis, although in this paper, we will not be considering the 'status' aspect of the hypothesis. We will confine our study to the impact of ICT sophistication on the reduction of "the barriers of time and space". We formulate our second hypothesis as such:

H2: The greater the degree of sophistication of the communication technology is, the more the interactions tend to be equivalent to face-to-face. In other words, the constraint of proximity is decreasing with the degree of sophistication of the communication technology;

We will test that hypothesis for each of the barrier we mentioned in section 2 other than trust (knowledge transfer, local characteristics of knowledge and the management of complex work). We chose to separate the issue of trust (H1), as, from the literature, it really seems more difficult to achieve through media.

To gather elements for the answer to our hypothesis, we proceeded to a case study. In order to know if technologies will allow scientists to take up the challenge of remote collaboration, we investigated the real-life context of plasma physics.

4. The International Sun-Earth Explorers (ISEE) Project

We proceeded to an empirical enquiry in the field of space physics. It provides us with an in-depth understanding of virtual collaboration. We focused on one of the French teams who participated in the ISEE projects. They are specialised in the study of electromagnetic waves, one of the essential aspects of space plasma physics. We proceeded to interviews and e-mail contacts, so as to understand the organisation and management of remote collaboration. In a

[17] "Despite the expense, managers should allocate resources to let their employees travel to relevant distant sites early in the history of joint projects. This travel provides the face to face contact necessary to establish common ground, or meeting the mind, that might otherwise be diminished by distance." Rocco et al., 2001, p. 24

first approach, we present the projects and why we consider them as constituting a collaboratory (4.1.). Then, we introduce our methodology, based on the decomposition of technologies according to Atkins (1993) (4.2.). In each category, we observe a significant evolution in the degree of sophistication since the origins of the projects -1977 (4.3.). At last, we emphasise the complementarity of all the communication media.

4.1. Outline of the project

The ISEE program is an international co-operative program between NASA (National American and Space Agency) and ESA (European Space Agency) to study the interaction of the solar wind with the Earth's magnetosphere. The program used three spacecrafts, a mother/daughter pair (ISEE 1 and 2, from 1977 to 1987) and a heliocentric spacecraft (ISEE 3, later renamed ICE, from 1978 on). The purposes of the mission are fourfold:
(1) to investigate solar-terrestrial relationships at the outermost boundaries of the Earth's magnetosphere;
(2) to examine in detail the structure of the solar wind near the Earth and the shock wave that forms the interface between the solar wind and the Earth's magnetosphere;
(3) to investigate motions of and mechanisms operating in the plasma sheets;
(4) to continue the investigation of cosmic rays and solar flare effects in the interplanetary region.

A transdisciplinary and international project

The three spacecrafts carried a number of complementary instruments for making measurements of plasmas, energetic particles, waves and fields. The number of datasets is illustrated in table 4.

	Experiments	*Datasets*
ISEE 1	14	118
ISEE2	8	63
ISEE3 (up to Sept. 2000)	15	86

Table 4. Number of datasets

The setting and exploitation of the experiments is very complex in the sense that it requires the skills of several scientists from different sub-disciplines of space physics at the same time. A transdisciplinary approach was then called for. Consequently, no single laboratory can undertake such a program on its own, because of human as well of budget resources limitations. The ISEE project thus brought together scientists from all over Europe and the United States, every lab being specialised in a particular sub-discipline of space physics. For instance:

Sub-discipline	*Location of the lab*
Study of the plasma waves	U. of Iowa; USA
	Nasa Prop. Lab, USA
Study of the medium energy particles	Max Planck für Aeronomie, Ger
	Applied physics Lab., USA
	Los Alamos Nat. Lab., USA
Study of plasma density	Obs. de Meudon, Fr
	British Antartic survey, UK
Study of solar wind ions	Space Plasma Lab., Roma, It;

Table 5. Heterogeneity of partners involved in the ISEE projects

The different participating laboratories were selected on the basis of the replies received to a competitive Announcement of Opportunity issued jointly by the NASA and the ESA, the different laboratories each being funded by their national sponsoring agency. Our case study reflects the perceptions of one of the selected French laboratories.

The research infrastructure

Each satellite was operated from a unique agency (NASA or ESA). Nonetheless, as a transdisciplinary approach is required, the setting and the following up of the experiments were undertaken in dialogue with all the partners of the project. The members then had to face "the simultaneous need to solve problems of control and operation of instrumentation over the Internet, of access and distribution of datasets, and of convenient and flexible interaction with colleagues" (cf. 3.2.). Even though, here, members of the project do not directly control the satellite through the Internet, they still have an opportunity to do it indirectly, through their interactions with the operating agency. We will then regard this project as a collaboratory.

4.2. Methodology

Many technologies were made use of, at different levels of the cooperation. First come the technologies to interact between members (linking people to people). They are used before launching the explorer and during the experiment (basically, the information and knowledge shared are about satellite operating issues). Then the technologies to transmit the data from the satellite (linking people to "raw" information), to the operating Space Agency. In a third step, after they have been processed, data sharing and recording technologies are at stake (linking people to information). These technologies considerably evolved and improved with time, as we are going to explain it. A last category concerns technologies to link people to the infrastructure. We will not develop this last category, as the French team (who is the entry point to our case study) did not have access to these technologies.

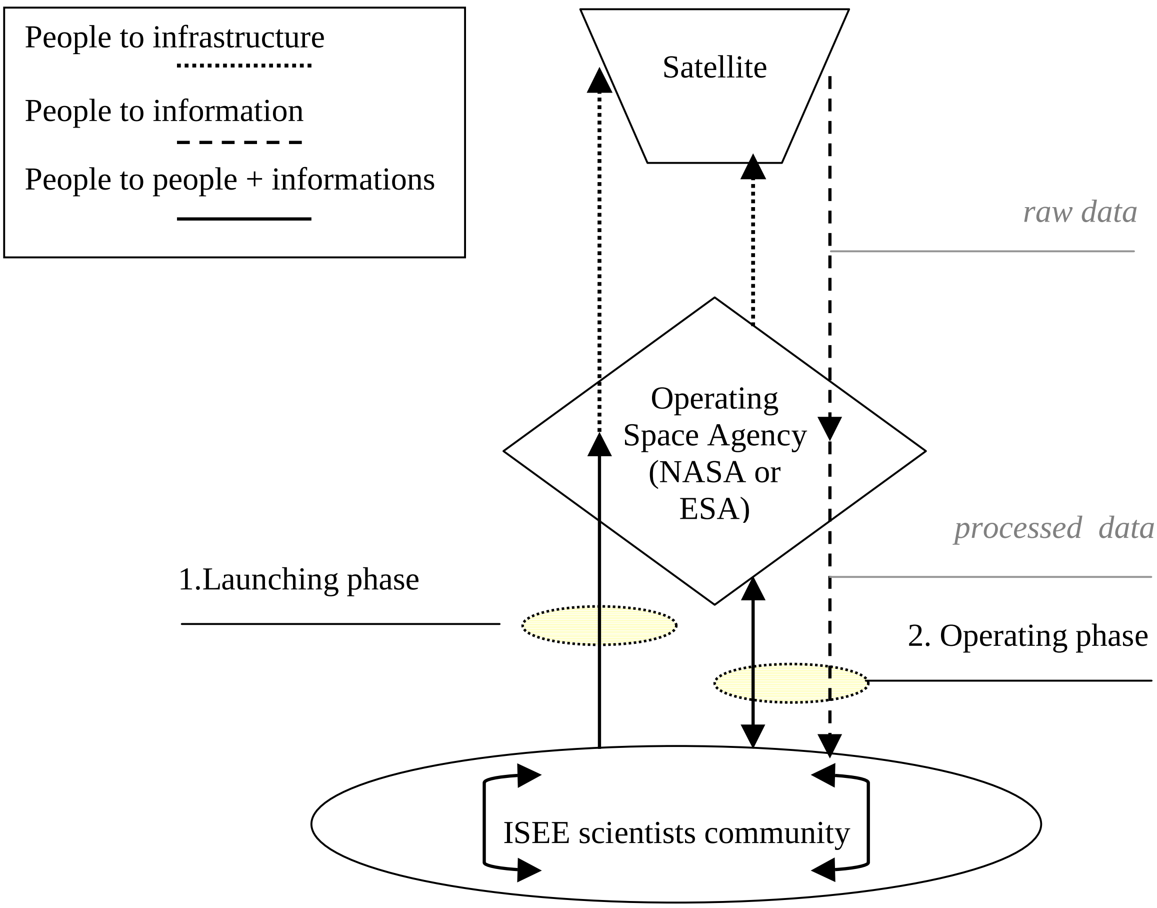

Figure 5. Technologies used in ISEE

In a first step, the satellite is launched after all members participate to the elaboration of the mission assigned (1. Launching phase). In a second step, and during its whole life, each explorer is operated according to the on-going data, gathered and processed by the operating agency and then transmitted to the scientific community (2. Operating phase).

4.3. Evolution of the technologies

We now come to the analysis of the ISEE projects. We are going through the evolution of the technologies, and the improvements in their degree of sophistication, and we evaluate their capacities to overcome the constraint of proximity. We distinguish the two forms of technology: people to people and person to information.

Technologies to link people to people

Here, we develop how knowledge transfer is done, if externalities can flow through ICT and the question of trust development. It is to notice that even if we insist on communication mediated through technologies, the interviewees emphasised the utmost importance of initial face-to-face.

Transfer of knowledge

As we have previously presented, the typology by Cowan & al. establishes 4 types of knowledge according to the level of codification (existence of codebook) and knowledge visibility. These cases are symbolised by: presence of codebook, displaced codebook, codebook unstabilised yet and no codebook. As we have explained, the means of communication differ according to the nature of knowledge. In the case of the ISEE projects, we note an evolution in each box.
Reminder:

	Manifest knowledge	Latent knowledge
Codified knowledge	Codebook explicit	Codebook displaced
Uncodified knowledge	Unstabilised codebook	No codebook

Table 1. Classification of knowledge according to the level of codification and manifestation of knowledge
Reference: from Cowan & al. (2000), 235

In the project, transatlantic cooperation was achieved through post mail. Thus, the American teams would send by post their projects of article to France. Then the French team would complete the first version and send it back by post. It could take about three weeks, as the scientists could not always answer by return of post. The transatlantic cooperation was then a failure as, when American researchers received the answer, they had often already changed their ideas or interpretation. Things even got worse when the American researchers implemented their own information system called the "Space Physics Analysis Network" which was a precursor of the Internet[18]. Through this tool, American scientists could achieve cooperation with geographically remote scientists (in the United States) quickly as they did not have to bear the time delay of post mail. Then, it appeared to French scientists that it was urgent to develop tools to build a network as well.
It was only in 1986 that the French team managed to obtain a transatlantic connection, as they started cooperation on the ISEE3 project[19]. This reduced the time delay between the two continents and improved the quality and efficiency of collaborations even if the flow of information was still very low. This was the time of the beginning of electronic distant cooperation. Referring to table 1, we can analyse this evolution as affecting the north-west corner, where knowledge is codified and manifest.
At that time, the researchers worked with DECnet protocol (developed and owned by Digital Equipment Corporation). Since the Internet revolution (1991), they use the TCP/IP protocol. They reduce the problems of system compatibility but networks users sometimes have to face security problems.

The use of ICTs for codified and manifest knowledge allows to reduce delays (compared to post mail) and to save time for the realisation of project.

[18] SPAN even offers a higher security system than the Internet.
[19] ESA was first connected in September 1985.

In the opposite corner of the typology (south-east corner, where no codebook exists), our interviews point out that communication was first achieved through face-to-face, as tacit knowledge requires practical and visual experience. Nonetheless, in the continuity of the ISEE project[20] (related to data stocking and sharing), teleconference was used as a complementary technology to face-to-face and trips. According to what we explained in section 2, the use of teleconference cannot allow the most efficient transfer of "traditional" tacit knowledge, as the visual part of communication is missing. However, in order to attest the utility of teleconference in transferring tacit knowledge, we think that it is worth establishing a distinction between intellectual and practical tacit knowledge. The latter is difficult to transmit without face-to-face. The former can be exchanged by partners who are cognitively close. In this case, geographical distance is much less important if the pre-requisites presented in section 2 are met. In fact, if people interact with a relatively high frequency, they become acquainted with the way people think, their competences. In other words, they learn to identify heuristics used by partners. Intellectual tacit knowledge can be transmitted through frequent phone calls, and even through some exchanges of written articles. Our case study illustrates that point, as the frequent use of teleconference (once a month) allowed the reduction of the number of trips to the United States, from four a year to one a year.
However, if we can conclude that sophisticated technology can allow tacit knowledge transfer, our case study does not allow us to conclude on the impact of ICT on the level of tacit knowledge codification.

In the case of non-stabilized codebook (south-west corner), the exchange of knowledge requires interactions in order to build a common code. In the ISEE project, the development of teleconference has enabled to decrease the importance of physical relations. This sort of relationship allows to exchange ideas which are not yet perfectly codified. In fact, the use of teleconference enables the French team to build new knowledge with remote partners and increases codification.
Thus, for the knowledge not yet stabilized and for knowledge with no codebook, the need for physical proximity is little to little and partially replaced by teleconference.

Our interviews revealed that during teleconferences some partners do not understand what others talk about. We compare this situation with the transfer of latent codified knowledge. This knowledge is not tacit but it seems so for the non-initiated, as he cannot find the codebook. Actually, this type of knowledge appeals to several disciplines of space physics and science in general, not explicitly linked with the problems people are facing.
In fact, we consider that this knowledge refers to common knowledge of a scientific community or a specific group. Some scientific rules are so much used than the scientists do not refer to the codebook explicitly when they use it.

The results of the transfer of knowledge according to the level of codification and manifestation of knowledge are summed up in the following table.

[20] Sharing access and distribution of datasets is one of the three activities that define collaboratories.

Degree of codification & of manifestation	1975	1980	1985	1990	1995
Visible codebook	Post mail		E-mail (proprietary system)	E-mail by TCP/IP protocol	
Displaced codebook	Post mail Face To Face		E-mail (proprietary system)	Teleconference e-mail	
Non-stabilized code Book	4 visits/year partially teleconference Long stays			1visit/yearshort stay	
No codebook					

Table 6 : Evolution of people-to-people technologies in the ISEE projects

Cumulativity and spillovers

As we mentioned in our introduction of the case study, space physics is a complex domain. The role of interactions is then reinforced as teamwork is needed. For the ISEE 1 experience, French researchers had to stay for a long time in the United States to set the experiment. Today, with the use of ICTs, frequent physical interactions are becoming less compulsory. In fact, teleconference allows exchanges of ideas, of information… so that it is partly replacing face-to-face interactions.

The use of teleconference as a complementary technology is efficient because it allows synchronised communication, that enables rapid interactions and confrontations. Then, e-mails are only used to complete teleconference with codified knowledge. For instance, before and after the meetings, partners can exchange information about the topic of the conference (processed data evaluation, etc.). Occasionally, researchers resort to face-to-face when they are facing serious problems.

As a result, it is interesting to note that with the frequent use of ICTs, in our case study, laboratories become more specialised. We can identify two reasons which are strongly linked to that phenomenon. Improvement of terrestrial infrastructures (opposed to “space” infrastructure) is the first reason of specialisation. Since the first experience, technical and scientific progress enables to develop more sophisticated tools in each sub-discipline of physics. The use of those new machines may require more specific competences. Moreover, the multiplicity of tools increases the cost of building a laboratory. Furthermore, the development of networks reinforced the process of specialisation as the need for developing competences is not compulsory anymore since you can communicate with other physicians who master them. Thus, the first experience the French team realised on ISEE 1 was entirely done “from A to Z” by themselves (they built electronic components, cables…). Today, each research centre is specialised. Therefore, they accomplish less and less tasks on each experience but they participate to more and more of them.

Comparatively, if ICTs allow remote and efficient meetings, they reinforce the need for interactions, as people are more and more interdependent. Thus, for each experiment, the number of trips decreases but the total number of trips does not decrease so much.

As teleconference allows remote interactions, we conclude that through this means, some spillovers are transmitted. If we refer to the second section, Autant-Bernard and Massard (2000) have shown that inter-personal relations are important vectors of knowledge diffusion. We recognise however, that it is difficult to identify them through a case study.

As we explained before, the organisation of space physics does not allow geographical proximity. In that respect, ICTs improve the life of the community as they facilitate the diffusion of knowledge. Nonetheless, the use of ICTs has the negative consequences on the life inside the laboratory. The scientists tend to work more with remote researchers than with their local colleagues.

The case study also underlines the difficulties of managing research projects at a distance. Indeed, if some operating issues of the project can be decided through teleconference, the serious problems of management require face-to-face, even if you know very well your counterparts. However, unlike what we thought, there seems to be no problems of coordination during teleconferences.

Trust and pre-requisites

Finally, as a result of interactions, the case study shows the importance of trust for remote relations. The belonging to researchers community is not sufficient to develop stable relations. In fact, trust is more inter-personal, built with time thanks to geographical proximity and frequent meetings. As supposed above, cognitive trust, unlike intentional trust, can be developed through the identification of potential partners at congress, colloquies, by reading articles and so on.

It is worth noticing that in virtual relationships, trust must be established before starting. This is verified for interpersonal and intentional trust. In fact, remote collaboration is possible only because the scientists know each other very well and for a long time (more than 20 years). Initial trust is then compulsory to communicate with remote physicians as they can imagine non-verbal reactions. Moreover, this trust does not rest only on scientific relations. The researchers exchange personal information. This is, as some behaviourist studies (University of Michigan) showed, a means to make trust last. However, if initial trust is required to establish remote relationships, trust must be "maintained". This must be effected through face-to-face, to "keep in touch ". It is the last but not the least reason for the maintaining of trips, even if those latter are always seen as a constraint.

Even if we focus on trust, the case study shows that the relations shared by partners include a larger notion than the simple conception of trust. In fact, they trust each other and they know each other too.

Technologies to link people to information

Technologies to link people with information mainly evolved relatively to the speed of communication and the extension of the diffusion; we will then deal with the diminishing barriers of time and space. On another point of view, we will deal with two separate problems that are managing the flow and managing the stock of information.

The management of the flow of information

With regards to the flow of information, both the speed and the wide diffusion of data are of importance. If the scientists have a fast access to the data of the satellite, they can react and adapt the next experiments. Besides, in emergency situations, the speed of transmission can ensure the well functioning of the operations. For instance, if the satellite detects a magnetic storm and informs the scientists immediately, they are 1 ¼ hour ahead of its arrival on earth. The detection of a magnetic storm is very important for the experiments on board the satellite, as electronic components get irradiated, which leads to electronic failures. Knowing the event on time, the scientists can switch off the operating system until the next orbit (within 3 days), or re-route the satellite[21].

The data from the satellite are gathered by only one antenna. The work is then to be done between the collecting agency (NASA or ESA and the other members of the community. The implementation of the transatlantic connection, in 1986, was the first step towards a wide and rapid connection to information. The flow of information was then very low (9,6 kbits/s) but still, data could be collected and diffused within 24 hours. It considerably improved the co-operation among the several research units.

A second step was recently achieved, as two new patterns of diffusion were developed in the last decade. According to the need of speed of access to the data, the research units can now choose between having an Internet access to some of the data (about 5%) or receiving the whole datasets on CD ROMs. The second option is the "normal" way of diffusion. The Internet display is restricted to a small number of units, who have a monitored access. Both of these patterns allow a geographically wide diffusion of information. They both have emerged because of the increase in the amount of data.

The management of the stock of information

Managing the stock of information seems to be a very important issue in our case study. The number of experiments led on the three satellites generated a huge amount of data and information. Until the end of the 1980s, keeping a record of data was considered as a final operation (it was compared to a burial). The emergence of computer networks gave birth of a new conception of information stocking, more interactive, with an easy access to old and recent data. At that time, the European members of the ISEE projects developed their own data stocking system: the European Space Research System (ESRS). Because of technical (as well as budget) limitations, the system had to be stopped in 1991. Once again, the development of an isolated system proved to be a rather inefficient solution, even though it led to some lessons for the future. For instance, it became obvious that the scientists had to be involved in the building of the network (and not only computer engineers); it also appeared that the whole community had to be included (all sub-disciplines need to work together so as to define "universal" searching methods and display of data).

The stocking of information is now done through CORBA (name of the system). Any scientist can send his or her files to be saved and the people in charge decide how to stock the information (according to the size of the file and the supposed frequency of use). The interfaces are adapted to the different disciplines of space physics. This new stocking centre allows a better access (in terms of time and space) to the research community.

[21] They can also take advantage of that time delay to warn the electricity companies (a magnetic storm is sometimes the cause of huge electricity failure), or warn the airplane companies to fly lower (in order to protect the flying personnel and the passengers).

The scientists are now mainly confronted to the problem of the adaptation capacity of the software. Almost every research unit has a different exploitation system (Linux, Mac, Sun, …), and every upgrading of the software leads to a wide variety of adaptation problems.

The technologies used to link people to information are summed up in table 7.

	1975	1985	1995
Flow of information		Transatlantic connection	Internet display CD ROM
Stock of information		<u>ESRS</u>	?

Table 7. Evolution of people-to-information technologies in the ISEE projects

4.4. On the complementary use of the communication patterns

To conclude, the case study illustrates the theoretical elements we have put in evidence in sections 2 and 3.
Table 8 sums up the different tasks completed today through the two main means of communication. Some tasks remain compulsorily achieved through face-to-face.

ICTs	*Face to face interactions*
Preparation of the launching phase Operating phase: - Analysis and interactions to improve the experiments - Routines in the collaboration process	Trust formation Launching meeting Trust maintenance Serious problems

Table 8: Tasks and functions realised through the two different means of communication

This table clearly synthesizes the complementarity of the means of communication. We notice that along time, a complementarity has been established, but still, ICTs could never substitute face-to-face interactions.

5. Conclusion and recommendations

Verification of the hypothesises

The "trust need touch" hypothesis is verified. Indeed, in our case study, the use of teleconference is efficient only because the remote physicians have known each other for 20 years. Besides, the use of teleconference, and sophisticated ICTs in a more general way, never suppressed the need for face-to-face communication. Even synchronisation and high quality communication channels could not supersede physical attendance. That result is not surprising. There is a consensus in the economic literature on that point. E. W. Steinmueller notes that "it is important for the group to have some degree of trust and mutual regard for such a system to work, otherwise individuals will not regard the 'solutions' or 'ideas' of others to be worth the time it takes to become aware of and evaluate them in a new context" (Steinmueller, 2000, p.367).

As for the "peripherality" hypothesis, the conclusion is less clear. On the one hand, if we consider one project at a time, the use of ICTs allows to reduce the constraint of geographical proximity. On the other hand, it has been underlined in our case study that the total number of trips has not decreased. This is due to the increase in the number of projects. This restriction to the validation of the hypothesis only concerns people-to-people technologies. The sophistication of people to information technologies completely overcomes the barriers of time and space. Remotes databases and other data sets, can indeed be shared and accessed in seconds from around the world and round the clock.

Side comments

The use of ICTs is very satisfactory in that it enables efficient remote collaboration. Collaboratories are transforming the way in which people create, accumulate; store and transmit information and knowledge, and the way in which they perform and react in their working environments. Furthermore, through encouraging interdisciplinary research, the innovation and knowledge discovery processes take place in new and often unexpected ways.

Yet, the use of ICTs is not neutral with regards to working patterns. As we mentioned in the case study, it engenders changes in both the nature and the organisation of scientific research. First, the division of labour is affected in the sense of an over specialisation, which increases the inter-dependence between research units. Then, the life within each participating laboratory is negatively impacted. It comes out from our case study that researchers deplore the fading of working and social interactions among local scientists.

Limits of our case study

A first limit to our case study is that the French team was never in touch with people-to-infrastructure technologies. An other bias regards the English speaking competences of our interviewees. Surprisingly, the two researchers interviewed were English speaking natives. It clearly facilitated the participation of the French team to an international project.

Recommendations

The fragmentation of the European research effort has been identified as a compounding factor in Europe's under-performance in the scientific arena. The Commision's Communication on the implementation of the European Research Area (ERA), adopted in January 2000, clearly states that the " decompartimentalisation and better integration of Europe's scientific and technological area is an indispensable condition for invigorating research in Europe".
Much progress has been made in recent years in the development of computer networking facilities in Europe.

From our study, we can conclude on the merit of such a policy from a scientific viewpoint. Nonetheless, we identify several rationales to limits the negative social impact of virtual networks. The analysis of trust underlines the importance of face-to-face interactions. Thus, complementary measures to public funding should be:

- Kick-off meetings must gather all members of the project in the same place.
- A minimum number of physical meetings has to be organised.

If both of these conditions are not met, we consider that the remote collaboration will not be able to produce new knowledge in an efficient way. Thus, it will not be reliable.

Moreover, so as to avoid the deterioration of the life within local laboratories, we propose to condition the public funding to the respect of some indicators of local and social dynamism such as “local” co-publications, local events…

The last but not least of our recommendations deals with the need to mix computer scientists with technology users in order to implement well-suited tools (adapted to the real requirements of users).

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